2.0 IWEM Overview

The IWEM software developed by the EPA provides a two-tiered analysis that requires a minimum of data. The analysis produces recommendations for the type of liner to be used in a WMU and/or whether land application is appropriate. The two-tiered analysis is presented within a user-friendly, Windows-based program called IWEM. IWEM will operate on any standard personal computer using Windows™ 95 or later operating system (see Section 3.0 for system requirements). A brief overview of IWEM is provided in the remainder of Section 2.0.

2.1 What does the software do?

The IWEM software is designed to assist you in determining a recommended liner design for different types of Resource Conservation and Recovery Act (RCRA) Subtitle D (non-hazardous) WMUs. IWEM compares the expected leachate concentration[2] entered by the user for each waste constituent with the leachate concentration threshold value (LCTVs)[3] calculated by a ground-water fate and transport model for three standard liner types[4].

The IWEM software compiles the results for all constituents expected in the leachate and then reports the minimum liner scenario that is protective for all constituents. Table 2.1 shows the combinations of WMUs and liners that are represented in IWEM. For LAUs, only the *no-liner* scenario is evaluated because liners are not typically used at this type of facility.

The IWEM software supports file saving and retrieval so that evaluations can be archived or retrieved later and modified. The software also has report generation capabilities to document in hard-copy the input values and resulting liner recommendations.

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[2] The expected leachate concentration means the concentration, in milligrams per liter (mg/L), of each constituent of concern that is expected to be present in the leachate after emplacement of the waste in a WMU. Typically this concentration is measured using a laboratory leachate test. Chapter 2 (Characterizing Waste) of the ***Guide*** provides more information on selecting a leachate test.

[3] The LCTV represents the maximum allowable leachate concentration that is protective of ground water; if the expected leachate concentrations of all constituents are less than their LCTVs for a particular waste management scenario, then we recommend you select that WMU design to manage that particular waste.

[4] The three liner designs in IWEM are: no liner, single clay liner, and composite liner (see Table 2.1).

Table 2.1 IWEM WMU and Liner Combinations

WMU Type	Liner Type		
	No Liner (in-situ soil)	Single Clay Liner	Composite Liner
Landfill	✔	✔	✔
Surface Impoundment	✔	✔	✔
Waste Pile	✔	✔	✔
Land Application Unit	✔	N/A	N/A

N/A = Not applicable

2.1.1 Tier 1 Evaluation

In a Tier 1 evaluation, the required inputs are the WMU type you wish to evaluate, constituents of concern, and the expected leachate concentration for each constituent of concern. After providing these inputs, IWEM determines a minimum recommended liner design that is protective for all waste constituents. This determination is made by comparing the expected leachate concentration for each constituent to tabulated values of liner- and constituent-specific LCTVs, and identifying for which liner designs the LCTV of each constituent is equal to, or greater than the input value of expected leachate concentration. IWEM incorporates LCTV values for 206 organic and 20 metal constituents (see Appendix A) that are part of the software's built-in database. These LCTVs were generated by running **EPA**'s **C**omposite **M**odel for Leachate Migration with **T**ransformation **P**roducts (EPACMTP, described in Section 2.2.2 below) for a wide range of site conditions expected to occur at waste sites across the United States.

The process used to simulate varying site conditions is known as *Monte Carlo analysis*. The Monte Carlo analysis determines the statistical probability that the release of leachate would result in a ground-water

About Monte Carlo Analysis:

Monte Carlo analysis is a computer-based method of analysis developed in the 1940's that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation or model. The name refers to the city on the French Riviera that is known for its gambling and other games of chance. Monte Carlo analysis is increasingly used in risk assessments where it allows the risk manager to make decisions based on a statistical level of protection that reflects the variability and/or uncertainty in risk parameters or processes, rather than making decisions based on a single point estimate of risk. For further information on Monte Carlo analysis in risk assessment, see the EPA's *Guiding Principles for Monte Carlo Analysis* (U.S. EPA, 1997).

concentration exceeding regulatory or risk-based standards. The Tier 1 LCTVs, are designed to be protective with 90% certainty for possible waste sites in the United States.

The advantages of a Tier 1 evaluation are that it is fast and does not require site-specific information. Tier 1 is designed to be a screening analysis that is protective for most sites. This means that a Tier 1 analysis may result in a liner recommendation that is more stringent - - and costly to implement - - than is needed for a particular site. For instance, site-specific conditions such as low precipitation and a deep unsaturated zone may warrant a less stringent liner design.

2.1.2 Tier 2 Evaluation

A Tier 2 evaluation utilizes information on the unit's location and other site-specific data enabling you to perform a more precise assessment. If appropriate for site conditions (*e.g.*, an arid climate), it may allow you to avoid constructing an unnecessarily costly WMU design. It may also provide an additional level of certainty that liner designs are protective of sites in vulnerable settings, such as areas with high rainfall and shallow ground water.

To perform Tier 2 evaluations, IWEM runs a complete EPACMTP fate and transport simulation using site-specific input data, and generates a probability distribution of expected ground-water well concentrations for each waste constituent and liner scenario. It then compares the 90th percentile of the modeled ground-water well concentration to a reference ground-water concentration (RGC[5]) value (for instance, a regulatory maximum contaminant level (MCL)) until it has identified the liner design for which the 90th percentile of the expected ground-water concentration does not exceed the RGC.

IWEM is designed to allow Tier 2 evaluations with varying levels of available site-specific information and data. IWEM allows you to provide site-specific values for the most important modeling parameters, but if you have limited site data available, IWEM will use default values or distributions for parameters for which you have no data. IWEM will also assist you in making the most appropriate use of the information you have available. For instance, if you know that a site has an alluvial aquifer, but you do not have site-specific values for ground-water parameters such as hydraulic conductivity, IWEM will assign representative values for alluvial aquifers from its extensive built-in database of ground-water modeling parameters.

[5] See Section 6.1.4 (page 6-4) for a definition of RGC.

Tier 2 users can perform an evaluation for any of the waste constituents that are included in Tier 1; Tier 2 users also have the option to include additional waste constituent(s) and/or modify constituent properties in the default database. Specifically, you can provide constituent-specific soil - water partition coefficient (k_d) and degradation (λ) coefficients, and a user-defined RGC and exposure duration.

In many cases, a Tier 2 evaluation will allow a less stringent and less costly liner design than the Tier 1 screening analysis will allow. If a site is vulnerable to ground-water contamination, a Tier 2 analysis will allow you to determine appropriate waste management options and liner designs with greater confidence than a Tier 1 analysis. Chapter 4 of the ***Guide*** discusses siting considerations for WMUs, including how to recognize a vulnerable hydrogeological setting. The trade-off in performing a Tier 2 evaluation is that the fate and transport simulations are computationally demanding and can take hours to complete, even with a very fast personal computer. The reason is that the Tier 2 model simulations incorporate Monte Carlo analysis to handle the uncertainty associated with default values and other modeling parameters that are not user-specified.

2.1.3 Tier 3 Evaluation vs IWEM

If the IWEM Tier 1 and Tier 2 evaluations do not adequately simulate conditions at a proposed site because the hydrogeology of the site is complex, you may consider a comprehensive site-specific risk assessment. For example, if ground-water flow is subject to seasonal variations, performing a Tier 2 Evaluation in IWEM may not be appropriate because the model is based on steady-state flow conditions. A comprehensive site-specific ground-water fate and transport analysis may be required to evaluate risk to ground water and alternative liner designs or land application rates. This type of analysis is beyond the scope of IWEM. If appropriate, consult with your state agency and use a qualified professional, experienced in ground-water modeling. EPA recommends that you talk to state officials and/or appropriate trade associations to solicit recommendations

Why it is important to use a qualified professional?

- Fate and transport modeling can be very complex; appropriate training and experience are required to correctly use and interpret models.
- Incorrect fate and transport modeling can result in a liner system that is not sufficiently protective or an inappropriate land application rate.
- To avoid incorrect analyses, check to see if the professional has sufficient training and experience in analyzing ground-water flow and contaminant fate and transport.

for a good consultant to perform the analysis. For more details see Chapter 7A of the ***Guide***.

2.2 IWEM Software Components

The IWEM software consists of three main components (or modules): (*i*) a Graphical User Interface (GUI) which guides you through a series of user-friendly screens to perform Tier 1 and Tier 2 evaluations; (*ii*) the EPACMTP computational engine and integrated Monte Carlo processor that perform the ground-water fate and transport simulations for Tier 2 evaluations; and (*iii*) a series of databases of waste constituents, WMUs, and site-specific parameters. Each of these three components is discussed briefly in this section.

2.2.1 IWEM User Interface

When you use the IWEM software, you are interacting with the GUI module. This module consists of a series of data input and display screens, that enable you to define a Tier 1 and/or a Tier 2 evaluation; view and select parameter input values from IWEM's built-in database; enter your own site-specific data; and view the results of the IWEM evaluation. Figure 2.1 shows a sample IWEM user interface screen. A detailed description of each IWEM user interface screen is provided in Section 5 of this *User's Guide*.

If you are performing a Tier 1 evaluation, the software simply performs a table look-up of the Tier 1 LCTV tables that are built into the software for the WMU and waste constituent(s) you selected. Once you have specified all the Tier 1 data inputs, the results of the evaluation are instantaneously available for on-screen display or printing in a hard-copy report.

If you are performing a Tier 2 evaluation, the GUI will take you through a step-wise process of assembling the pertinent site-specific data. The GUI module also includes options to view and modify constituent-specific data, as well as add additional constituents to IWEM's constituent database. Once IWEM has gathered all your data, it will then run the EPACMTP model. Upon completion of the site-specific fate and transport simulations, IWEM will display the liner recommendation and generate a printed report if desired.

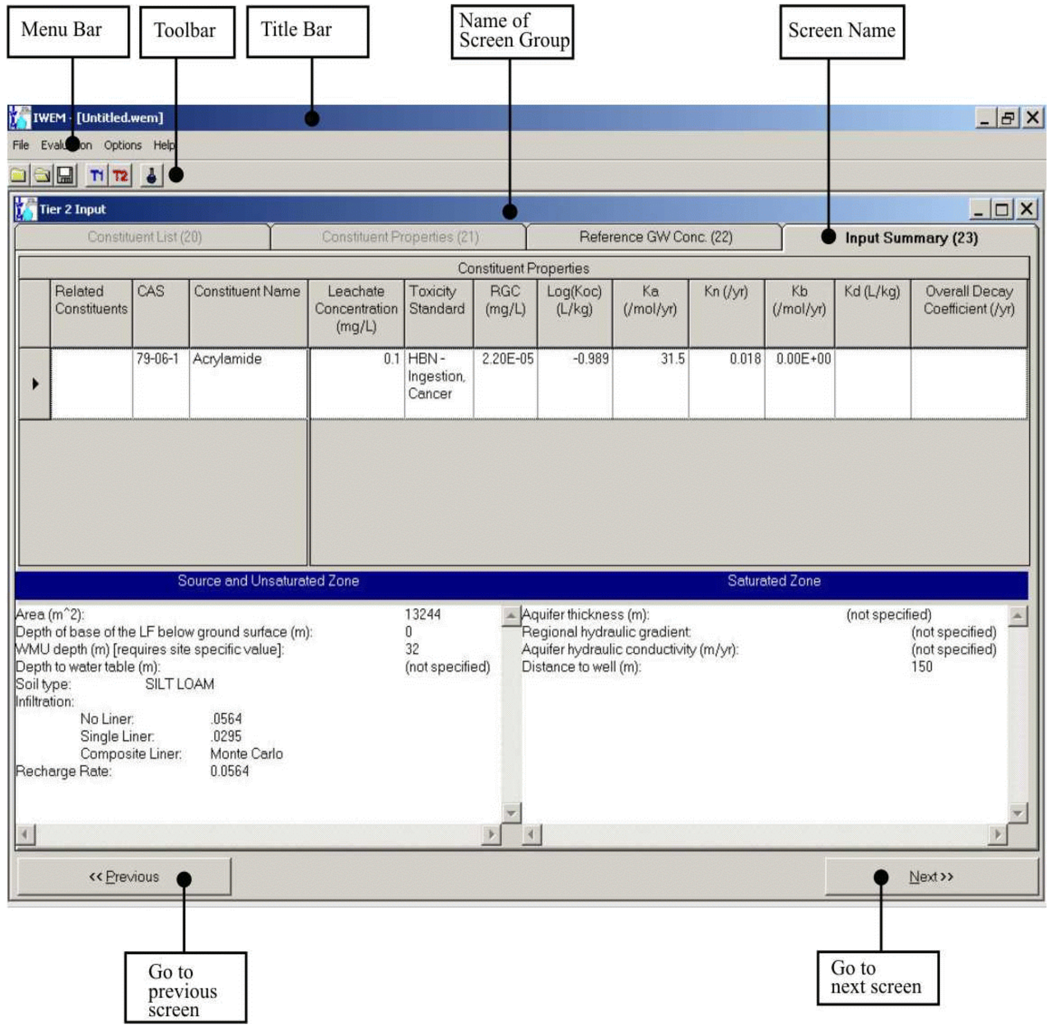

Figure 2.1 Sample IWEM Screen.

2.2.2 EPACMTP Fate and Transport Model

EPACMTP is a sophisticated fate and transport model that simulates the migration of waste constituents in leachate from land disposal units through soil and ground water. EPACMTP has been developed by EPA's OSW to support risk-based ground-water assessments under RCRA. EPACMTP has been applied to waste identification, hazardous waste listing and other regulatory evaluations. This *User's Guide* provides only a brief summary of the EPACMTP; a complete description of the model is provided in the *EPACMTP Technical Background Document* (U.S. EPA, 2002a). The *IWEM Technical Background Document* (U.S. EPA, 2002c) describes how we used EPACMTP to develop the Tier 1 and Tier 2 Evaluations in IWEM.

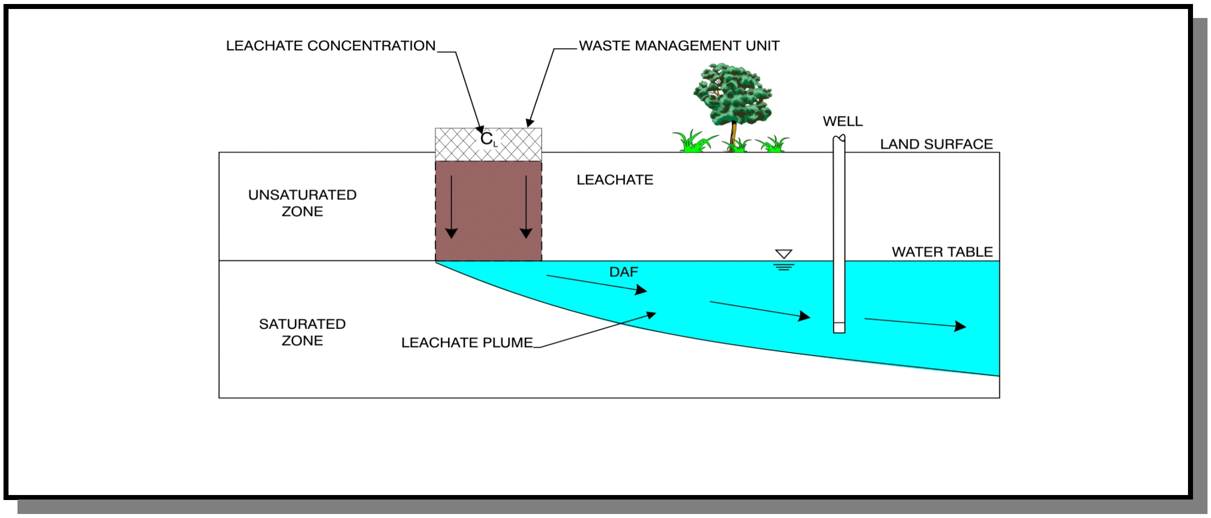

Figure 2.2 Conceptual View of Aquifer System Modeled by EPACMTP.

EPACMTP simulates fate and transport of constituents in both the unsaturated zone and the saturated zone. Figure 2.2 shows a conceptual, cross-sectional view of fate and transport modeled by EPACMTP. The source of constituents is a WMU located at or near the ground surface overlying an unconfined aquifer. Waste constituents leach from the base of the WMU into the underlying soil. They migrate vertically downward until they reach the water table. As the leachate enters the saturated zone, it will mix with ambient ground water (which is assumed to be free of pollutants) and a ground-water plume will develop that extends in the direction of downgradient ground-water flow. Although it is not shown in Figure 2.2, EPACMTP accounts for the spreading of the plume in all three dimensions.

Leachate generation is driven by the infiltration of precipitation that has percolated through the WMU into the soil. The type of liner at the base of the WMU affects the rate of infiltration that can occur and, hence, the release of leachate into the soil. EPACMTP models flow in the unsaturated zone and in the saturated zone as steady-state processes, that is, it models long-term average flow conditions. EPACMTP also simulates the ground-water mounding that may occur underneath a WMU with a high infiltration rate and its effect on ground-water flow. This may be significant, particularly in the case of unlined SIs. In cases of very high infiltration rates in settings with shallow ground water, EPACMTP may cap the infiltration rate to avoid having the modeled ground-water mound rise above the bottom of the WMU.

EPACMTP accounts for the dilution of the constituent concentration caused by the mixing of the leachate with ground water. EPACMTP also accounts for attenuation due to sorption of waste constituents in the leachate onto soil and aquifer solids, as well as bio-chemical transformation (degradation) processes in the unsaturated and saturated zone. These processes decrease constituent concentrations in the ground water as the distance from the WMU increases.

Sorption refers to the process whereby constituents in the leachate attach themselves to soil particles. For organic constituents, EPACMTP models sorption between the constituents and the organic matter in the soil or aquifer, based on constituent-specific organic carbon partition coefficients (K_{oc}) and a site-specific organic carbon fraction in the soil and aquifer. For metal constituents, EPACMTP accounts for more complex geochemical reactions by using effective sorption isotherms for a range of aquifer geochemical conditions, as generated using the MINTEQA2[6] geochemical speciation model.

In Tier 1 and as the default in Tier 2, EPACMTP only accounts for constituent transformations caused by hydrolysis reactions. Hydrolysis refers to constituent decomposition that results from chemical reactions with water. In Tier 2 analyses, however, you may also enter site-specific biodegradation rates. Biodegradation refers to constituent decomposition reactions involving bacteria and other micro-organisms. EPACMTP simulates all transformation processes as first-order reactions, that is, as processes that can be characterized with a half-life.

EPACMTP accounts for constituents which hydrolyze into toxic daughter products. In that case, the final liner recommendations are determined in such a way that they accommodate both the parent constituent as well as any toxic daughter products. For instance, if a parent waste constituent rapidly hydrolyzes into a persistent daughter product, the ground-water exposure caused by the parent itself may be minimal (it has already degraded before it reaches the well), but the final liner recommendation would be based on the exposure caused by the daughter product.

In Tier 2, IWEM makes liner recommendations by comparing ground-water exposure concentration values predicted by EPACMTP against RGCs that are either regulatory MCLs or cancer and non-cancer Health-Based Numbers (HBNs). For the IWEM analysis, the ground-water exposure concentration is evaluated at a hypothetical well that is located downgradient from the WMU. EPACMTP accounts for the finite life-span of WMUs, which results in a time-dependent ground-water exposure concentration. The exposure concentration calculated by EPACMTP is the maximum average concentration during the time period in which the ground-water exposure at the well occurs. The length of the exposure averaging period is adjusted to match the assumptions

[6] MINTEQA2 (U.S. EPA, 1991) is a geochemical equilibrium speciation model for computing equilibria among the dissolved, absorbed, solid, and gas phases in dilute aqueous solution.

incorporated in the RGC. For instance, when the ground-water exposure concentration is compared to a RGC that is based on cancer risk, the averaging period is set to 30 years; whereas for non-cancer effects caused by ingestion of water, EPA considered only childhood exposure, and set the averaging period to 7 years (covering the time period from birth through the 6^{th} year of life).

In both Tier 1 and Tier 2 analyses, the groundwater modeling results of the EPACMTP model are summarized by IWEM in terms of Dilution and Attenuation Factors (DAFs). A DAF is a numerical value that represents the reduction in the concentration of a constituent arriving at the modeled ground-water well as compared to the concentration of that constituent in the waste leachate. A DAF value of 10 means that the concentration at the well is 10 times less than the concentration in the leachate. Using DAFs is a convenient way to go back-and forth between leachate concentrations and exposure concentrations, or ground-water reference concentrations.

2.2.2.1 IWEM vs. EPACMTP

As an IWEM user, you should understand the differences between IWEM and EPACMTP. EPACMTP is a full-featured ground-water flow and transport model with probabilistic modeling capabilities; it is a sophisticated software program which requires a significant amount of computer and ground-water modeling expertise to create the necessary input files, execute the model, and interpret the results.

In contrast, IWEM is a relatively simple and user-friendly program created specifically to conduct Tier 1 and/or Tier 2 analyses of the ground-water pathway within the context of the EPA's ***Guide***. Specifically, within Tier 1, IWEM can be used to query a database of existing EPACMTP modeling results in the form of LCTV values, and to analyze these tabulated results to produce a Tier 1 WMU design recommendation that is specific to your waste. Within Tier 2, IWEM converts your input values into the required EPACMTP input files, executes a series of EPACMTP modeling runs, and then compiles and analyzes the results to produce a Tier 2 WMU design recommendation that is specific to your waste and your waste site. In addition, for both tiers of analysis the IWEM software has the capability to print and save document-ready reports that include the liner recommendations and the input data on which they are based.

In summary, IWEM can be thought of as an application of EPACMTP that is tailored specifically for use in non-hazardous industrial waste management decision-making. In order to make IWEM appropriate and easy to use in performing these Tier 1 and Tier 2 analyses, not all of the EPACMTP functionality is available to the IWEM user; however, the IWEM provides added capabilities to interpret results and develop reports, which are not available within EPACMTP.

2.2.3 IWEM Databases

The third component of IWEM is an integrated set of databases that include waste constituent properties and other ground-water modeling parameters. The waste constituent database includes 206 organics and 20 metals. Appendix A provides a list of the constituents in the database. The constituent properties include physical and chemical data needed for ground-water transport modeling, as well as RGCs. These RGC's include: 1) regulatory MCLs, and 2) cancer and non-cancer HBNs for drinking water ingestion and inhalation of volatiles during showering. Section 7 of this *User's Guide* discusses how IWEM uses these RGC's to calculate LCTVs.

In addition to constituent data, IWEM includes a comprehensive database of ground-water modeling data, including infiltration rates for different WMU types and liner designs for a range of locations and climatic conditions throughout the United States; and soil and hydrogeological data for different soil types and aquifer conditions across the United States. Details of these databases are provided in the *EPACMTP Parameters/Data Background Document* (U.S. EPA, 2002b), and in the *IWEM Technical Background Document* (U.S. EPA, 2002c).

EPA used these databases to develop the IWEM Tier 1 LCTVs, and they are incorporated into the IWEM software to perform Tier 2 evaluations. When site-specific data are available for a Tier 2 evaluation, they will override default database values. Conversely, when site-specific data are not available for a Tier 2 evaluation, IWEM will use default values or random sampling of values from distributions in its databases to augment the user-provided data.

2.3 Assumptions and Limitations of Ground-Water Modeling

The tiered approach developed to evaluate WMU designs uses sophisticated probabilistic techniques to account for uncertainty and parameter variability. To perform the evaluations recommended by the ***Guide***, the mathematical models represent conditions that may potentially be encountered at waste management sites within the United States. Efforts have been made to obtain representative, nationwide data and account for the uncertainty in the data.

However, given the complex nature of the evaluations, a number of limitations and caveats must be delineated. These limitations are described in this section. Before using this software, you need to verify that the model assumptions are appropriate for the site you are evaluating. The *IWEM Technical Background Document* (U.S. EPA, 2002c) provides additional information to assist you in this process.

EPACMTP represents WMU's in terms of a source area and a defined rate and duration of leaching. EPACMTP only accounts for the release of leachate through the base of the WMU and assumes that the only mechanism of constituent release is through dissolution of waste constituents in the water that percolates through the WMU. EPACMTP does not account for the presence of non-aqueous free-phase liquids, such as an oily phase that might provide an additional release mechanism into the subsurface. EPACMTP does not account for releases from the WMU via other environmental pathways, such volatilization or surface run-off. EPACMTP assumes that the rate of infiltration through the WMU is constant, representing long-term average conditions; the model does not account for fluctuations in rainfall rate, or degradation of liner systems that may cause the rate of infiltration and release of leachate to vary over time.

EPACMTP does not explicitly account for the presence of macro-pores, fractures, solution features, faults or other heterogeneities in the soil or aquifer that may provide pathways for rapid movement of constituents. A certain amount of heterogeneity always exists at actual sites, and it is not uncommon in ground-water modeling to use average parameter values. This means that the input values for parameters such as hydraulic conductivity, dispersivity, etc. represent effective site-wide average values. However, EPACMTP may not be appropriate for sites overlying fractured or very heterogeneous aquifers.

EPACMTP is designed for relatively simple ground-water flow systems. EPACMTP treats flow in the unsaturated zone and saturated zone as steady state and does not account for fluctuations in the infiltration or recharge rate, either in time or areally. As a result, the use of EPACMTP may not be appropriate at sites with large seasonal fluctuations in rainfall conditions, or at sites where the recharge rate varies locally. Examples of the latter include the presence of surface water bodies such as rivers and lakes or ponds, and/or man-made recharge sources near the WMU. EPACMTP does not account for the presence of ground-water sources or sinks such as pumping or injection wells.

Leachate constituents can be subject to complex biological and geochemical interactions in soil and ground water. EPACMTP treats these interactions as equilibrium sorption and first-order degradation processes. In the case of sorption processes, the equilibrium assumption means that the sorption process occurs instantaneously, or at least very quickly relative to the time-scale of constituent transport. Although sorption, or the attachment of leachate constituents to solid soil or aquifer particles, may result from multiple chemical processes, EPACMTP lumps these processes together into an effective soil-water partition coefficient. In the case of metals, EPACMTP allows the partition coefficient to vary as a function of a number of primary geochemical parameters, including pH, leachate organic matter, soil organic matter, and the fraction of iron-oxide in the soil or aquifer.

Although EPACMTP is able to account for the most important ways that the geochemical environment at a site affects the mobility of metals, the model assumes that the geochemical environment at a site is constant and is not affected by the presence of the leachate plume. In reality, the presence of a leachate plume may alter the ambient geochemical environment. EPACMTP does not account for colloidal transport or other forms of facilitated transport. For metals and other constituents that tend to strongly sorb to soil particles, and which EPACMTP will simulate as relatively immobile, movement as colloidal particles can be a significant transport mechanism. However given sufficient site-specific data, it is possible to approximate the effect of these transport processes by using a lower value for the k_d as a user-input in Tier 2.

EPA's ground-water modeling database includes constituent-specific hydrolysis rate coefficients for constituents that are subject to hydrolysis transformation reactions; for these constituents, EPACMTP simulates transformation reactions subject to site-specific values of pH and soil and ground-water temperature, but other types of transformation processes are not explicitly simulated in EPACMTP. For many organic constituents, biodegradation can be an important fate mechanism, but EPACMTP has only limited ability to account for this process. The user must provide an appropriate value for the effective first-order degradation rate. In the IWEM application of EPACMTP, the model uses the same degradation rate coefficient for the unsaturated and saturated zones if this parameter is provided as a user-input in Tier 2 evaluations. In an actual leachate plume, biodegradation rates may be different in different regions in the plume; for instance in portions of the plume that are anaerobic some constituents may biodegrade more readily, while other constituents will biodegrade only in the aerobic fringe of the plume. EPACMTP does not account for these or other processes that may cause a constituent's rate of transformation to vary in space and time.